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The Aid Trade

International Assistance Programs as Pathways for the Introduction of Invasive Alien Species

A Preliminary Report

Sean T. Murphy
Oliver D. Cheesman
(CABI Bioscience, UK Centre)

March 2006

THE WORLD BANK ENVIRONMENT DEPARTMENT

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The Aid Trade — International Assistance Programs as Pathways for the Introduction of Invasive Alien Species

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Preface

An earlier version of the manuscript was prepared by first author on behalf of the Global Invasive Species Programme (GISP). GISP is an international coalition of biologists, natural resource managers, economists, and policy makers working to prevent the spread of harmful invasive alien species (IAS) through improved control systems and strategic long term planning. The identification of IAS introduction vectors and pathways (through accidental and deliberate introduction of species), and appropriate, targeted responses, are considered key to its success. In this context, GISP has identified the vectors and pathways associated with international assistance programs as being of particular concern.

Wherever possible, this report has been based on published sources to ensure that the information presented is reliable and traceable. This has highlighted one of the main constraints in reviewing the role that international assistance programs have played, and continue to play, in the introduction of IAS: very few specific accounts have been published. This lack of published accounts only emphasizes the extent to which the threats posed by IAS introductions have been overlooked thus far by many agencies engaged in international operations.

Because of the lack of published accounts of IAS problems associated with international assistance programs, much of this report outlines IAS problems that have arisen through activities *typically associated with* such programs, for example, agricultural and other development projects in a wider sense. This approach clearly illustrates the likely, substantial threat of IAS problems arising from international assistance. It should also be noted, however, that although the precise circumstances of many of the introductions described here are not detailed in the literature, anecdotal reports do link them to international programs. One of the recommendations made here is for an urgent, fuller assessment of the problem to allow a more thorough investigation. Nevertheless a number of precautionary actions could be taken already.

This discussion paper is sponsored by the World Bank and CABI, both institutions concerned with delivering development assistance. It was produced to raise awareness about the costs and problems associated with IAS and as a contribution towards promoting more environmentally sustainable development.

A number of people have provided valuable information and advice in the preparation of this report. In this regard, we are grateful to Megan Quinlan, Jeff Waage, John Bridge, Rob Reeder, Dennis Rangi, Peter Neuenschwander, Kathy MacKinnon, Chagema Kedera, Ravi Kheterpal, Robert Paterson, Carla Little, Jamie Reaser, Nick Pasiecznik, Jim Space, Gad Perry, Phoebe Barnard, David Duthie, Chris Buddenhagen, Ian Faithfull, Bob Ikin, David Le Maitre, Carnet Williams and Devinder Sharma for their contributions.

Executive Summary

It is now recognized that invasive alien species (IAS) pose a major threat to agricultural and natural ecosystems and to human health and livelihoods. These non-native species, which are accidentally or intentionally introduced into new areas, range from microbes to mammals. One of the major disturbing features of IAS problems is that they are on the increase globally. Reasons for the increased threat are multi-faceted and interlinked. Natural barriers to species movement have been breached over the last few centuries, but particularly in the 20th Century, through increased volumes and speed of international trade, transportation, and human movement. The enormous potential for accidental species introductions is demonstrated by the numbers of pest, disease, and other organisms intercepted by quarantine units tasked with the inspection of imported consignments. Such quarantine units are usually associated with the agricultural sector, within which the importance of having appropriate measures for the prevention and mitigation of IAS problems has long been appreciated. More recently, recommendations arising from Conference of the Parties (in particular COP5 and COP6) to the Convention on Biological Diversity have included the urgent need to protect the wider environment from IAS.

The precise origins of many existing IAS problems, particularly in the developing world, are poorly understood. This complicates assessments of the relative importance of different vectors and pathways for IAS introductions, and the prediction of future risks. The available information on IAS as a result of international assistance programs is scattered, poorly documented, and difficult to come by. Here, international assistance is taken to include development programs (particularly in relation to agriculture, (agro)forestry and aquaculture), disaster relief programs, and military assistance programs with a humanitarian remit (such as peace-keeping operations conducted under the auspices of the United Nations). In this review, a preliminary assessment is made of IAS problems resulting from these three types of activity. Because most accounts of IAS introductions under humanitarian assistance programs are anecdotal, the number of specific cases identified here is relatively small. Background information is therefore presented which illustrates how the types of activity typically associated with development programs are well known to contribute to the global spread of IAS. It is clear that the issue of IAS and international assistance warrants further and more extensive study.

International assistance programs can facilitate both deliberate and unintentional IAS introductions. Such misjudgments and accidents are costly; indeed, their negative effects may be far greater and more long lasting than the positive impacts of the aid programs from which they arose. Most of the major international aid agencies contribute support to agricultural and other development programs of developing countries. There is now good evidence that these activities have increasingly, and unwittingly, led to the introduction of species that subsequently became invasive. IAS accidentally introduced through development assistance programs include itch grass, a major weed in cereals in South and Central America, and a range of nematode pests. IAS problems resulting from intentional introductions under development assistance programs include water hyacinth and a number of agroforestry trees and shrubs. Ironically, in some cases, the very characteristics that make a species attractive for introduction under development assistance programs (rapid growth, tolerance of a range of environmental conditions, etc) are the same properties that increase the likelihood of the species becoming invasive.

Disaster relief and military assistance programs have also accidentally introduced some notable invasive species. For example, the larger grain borer now threatens stored maize across much of Africa, having been introduced with food aid shipments in the late 1970s. Western corn rootworm threatens maize production in the Balkans and neighboring parts of Europe, having been introduced accidentally with military equipment and personnel from North America in about 1992. Both of these species are still spreading in the affected regions.

IAS problems created by international assistance programs pose similar challenges to those arising through other vectors and pathways. However, two features make them a particular target for urgent, concerted action. Firstly, they are invariably directed at the most vulnerable human communities, where a loss of agricultural production or ecosystem services can have the most severe consequences for livelihoods. Secondly, they arise unintentionally from activities inspired by humanitarian motives, instigated by agencies with a strong interest in doing more good than harm. Such agencies would generally be expected to have both the human and financial resources to ensure that IAS problems are not imposed on the intended beneficiaries of their activities. Preventing or solving these particular IAS problems is therefore relatively more important and achievable than many other IAS problems, particularly in developing countries. A further important consideration is that quarantine systems are poorly developed and resourced in many (particularly small and/or developing) countries, and some importations, such as those associated with international assistance programs, may fall outside the scope of current prevention frameworks.

Knowing how, and from where, IAS are being introduced are important first steps in the development of effective prevention and early detection schemes. An urgent, and fuller, assessment is needed of the nature and severity of IAS threats associated with international assistance programs. Particular attention needs to be paid to vectors and pathways of movement. Part of the focus should be on case studies in order to elucidate more fully constraints in relation to existing prevention schemes. Nonetheless, some actions should be considered in advance, including awareness raising to aid agencies, and promoting the development of voluntary codes of conduct and risk assessments. All stakeholders should be involved in the process, in order to ensure equitable 'ownership' of responsibilities. Existing IAS problems that have resulted from international assistance activities also need to be addressed, although there may be conflicts of interest where an environmentally damaging species is making some contribution to local livelihoods.

1 Introduction

Invasive Alien Species, Vectors and Pathways

Although the phenomenon has been recognized for many years, the wide-ranging threats posed by biological invasions have come sharply into focus only in the last decade. Unfortunately, the precise terminology used to describe entities and processes in this field is yet to be unambiguously agreed. However, there is an increasing general acceptance that invasive alien species (IAS) are those alien [exotic, non-native] species which represent a threat to environments, economies and/or human health through their establishment in, spread through, and subsequent impacts on, areas from which they would ordinarily be excluded by natural barriers to dispersal. Implicit in this is the introduction of those species to new environments by some form of human agency, either deliberately or accidentally. The underlying mechanisms of introduction have been termed 'pathways', although there is an increasing trend to use this word to describe routes of introduction, and to use the term 'vectors' to describe the means by which species are moved along those routes. For further consideration of terminology see Reaser (2003) and similar papers in Macdonald *et al.* (2003b) and Shine *et al.* (2003b); Ruiz and Carlton (2003).

The threats to agricultural productivity posed by IAS (in the guise of weeds, pests, and diseases of crops and livestock) have long been recognized. However, the impacts of IAS on natural ecosystems, the services they provide, and wider human livelihoods and well-being have become more apparent only in recent years. For example, exotic plants can come to dominate freshwater bodies and waterways, affecting nutrient dynamics, oxygen availability, food webs and fisheries (Hill *et al*., 1999). It is now recognized that IAS, from microbes to mammals, pose a major threat to agricultural and natural ecosystems, and to human health and livelihoods (Mack *et al*., 2000). Examples of such impacts, as well as the economic costs of species invasions, are given by Reaser *et al*., (2003). Annual losses in the USA due to invasive plant pathogens total approximately US$23 billion; water hyacinth in Lake Victoria costs around US$150 million per year for control and removal, and threatens local fisheries; eradication of donkeys and goats from parts of the Galapagos Islands to protect fragile ecosystems, endemic species and the local tourist economy cost more than US$8 million. An epidemic of cholera, possibly transferred from South Asia in contaminated ballast water, ultimately cost over US$200 billion in control measures in Latin America. More detailed assessments of the costs of IAS impacts in a range of situations and localities are given by Pimentel (2002). In a number of cases, despite their negative impacts, invasive species do provide valuable resources for a proportion of the human population, resulting in potential conflicts of interest where control or eradication programs might be considered (for example, for trees and woody shrubs – Haysom and Murphy, 2003; Irby, 2004).

One of the most disturbing features of IAS threats is that they are on the increase, globally (Ruiz and Carlton, 2003). The reasons for this are multi-faceted and interlinked. Most importantly, in general terms, natural barriers to species movement have been increasingly breached over the last few centuries, and particularly in the 20th Century, through accelerating international movement of people and a wide range of materials. Developments in transportation technology have fuelled increasing trade, tourism, and other movements, providing for greater volumes and speed of international traffic. Other macro-factors, such as changing land-use and climate, may facilitate the establishment and spread of IAS once they are introduced to a new locality.

Whilst there is no reliable basis on which to accurately predict the likely invasiveness of a given species, a few broadly defined characteristics may tend to enhance invasive potential, including rapid growth rate, strong dispersal ability, large reproductive output, and broad tolerance of variation in environmental conditions such as temperature, water availability and pH (see Reaser, 2003 and similar papers in Macdonald *et al.*, 2003b; Shine *et al.*, 2003b). In some cases, these are precisely the kinds of characteristics which make an organism an attractive candidate for deliberate introduction, e.g. where objectives include high productivity, rapid formation of ground cover, etc. More generally, however, it should be noted that there is often a significant time lag (sometimes, several decades) before an introduced species becomes highly invasive.

The importance of adopting appropriate measures for the prevention and mitigation of IAS threats has long been appreciated by the agricultural sector. Increasing awareness of the threats to natural ecosystems has resulted in calls for similar measures in support of wider environmental protection. For example, the 1992 Convention on Biological Diversity (CBD) highlighted this need by instructing its parties to 'prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitats or species' (Article 8(h)). More recently, the Sixth meeting of the Conference of the Parties (COP6) to the CBD in the Hague adopted a set of Guiding Principles to tackle the global IAS threat.

Addressing IAS vectors and pathways

The identification of vectors and pathways, and appropriate, targeted responses are considered key to the success of countries, international organizations and others in mitigating the impact of IAS. The Global Invasive Species Programme (Box 1) has identified international assistance programs as potential pathways for IAS. This paper includes programs of development assistance (particularly in relation to agriculture, (agro)forestry and aquaculture), food aid and other disaster relief activities, and military assistance programs with a humanitarian remit (such as peace-keeping operations conducted under the auspices of the United Nations). The relative importance of these activities in providing vectors and pathways is largely unknown, but a number of examples exist of IAS introductions via such programs. These include deliberate introductions of species that have subsequently proven to be invasive, and the unintentional introduction of IAS into new areas. Such misjudgments and accidents are costly; indeed, their negative effects may be far greater and more long lasting than the positive impacts of the international programs from which they arose (Wittenberg and Cock, 2001; Baskin, 2002).

Box 1
The Global Invasive Species Programme (GISP)

GISP is a voluntary association between the World Conservation Union (IUCN), CAB International (CABI), The Nature Conservancy, USA (TNC) and the South African National Botanical Institute (SANBI) GISP has a small, dedicated secretariat in South Africa.

The GISP mission is to conserve biodiversity and sustain human livelihoods by minimizing the spread and impact of invasive alien species.

To this end, GISP seeks to:

- Improve the scientific basis for decision-making on invasive species
- Develop capacities to employ early warning and rapid assessment and response systems
- Enhance the ability to manage invasive species
- Reduce the socio-economic impacts of invasive species and control methods
- Develop better risk assessment methods, and
- Strengthen international agreements.

A key focus for GISP is to support the implementation of relevant international legal instruments such as the Convention on Biological Diversity.

The World Bank has formed a partnership with GISP by supporting the GISP secretariat and key capacity building activities with funding through the Bank Netherlands Partnership Program (BNPP) and the Development Grant Facility (DGF). Other international agencies have also supported the work of GISP.

For more information on GISP and its activities see www.gisp.org.

2 Invasive Alien Species — Dispersal and the Evolution of Vectors and Pathways

Understanding IAS Introductions in Terms of Species Dispersal

Dispersal is the process whereby a species moves from its place of origin to another locality (Udvardy, 1969). More precise and technical definitions have been proposed (e.g. Taylor, 1986) but the definition given here is sufficient for the purposes of this review. Various types of natural dispersal have been identified, including passive dispersal (including the movement of seeds on air or water currents – e.g. see Mack, 2003a), active dispersal (e.g. by flight, in the case of many birds and insects) and chance events (e.g. the 'rafting' of various species on floating driftwood). Such means of dispersal are essential for the movement of individuals within the native range of a species, or for the natural expansion of that range.

The dispersal strategies of different organisms have evolved over time in response to environmental conditions, and the extent of natural dispersal ability varies considerably between species. Nonetheless, on a broad geographical scale, dispersal has been limited by natural barriers and harsh environments that cannot be crossed, except by chance. Typical examples include oceans, mountain ranges and deserts, although equally formidable barriers exist at smaller spatial scales for many organisms. These barriers have, over the course of the Pleistocene, come to define the natural pattern of distribution of species over the globe. The confinement of populations to particular areas has been a key factor in the evolution of species, and the local and regional variability (and overall global richness) of biodiversity.

With the development of human activities over the last few millennia, new opportunities for species to breach biogeographical dispersal barriers have been created. Deliberate and accidental introductions (human-mediated dispersal events) have led to a dramatic increase in the number of species arriving in new localities. The proportion of introduced species that become established is relatively small, as is the proportion of established species that come to pose a significant threat as invasive alien species. It has been suggested that the proportion in each case is around 10% (the basis of the so-called "tens rule" - Williamson, 1996). Nonetheless, with increasing rates of introduction, species invasions arising from human-mediated translocations are sufficient to threaten the global patterns of biodiversity which have developed within and between natural barriers to dispersal (Vitousek *et al*., 1997).

The Impact of Human Activity on the Movement of Species

Introductions can be intentional (deliberate) or unintentional (accidental), and the reasons underlying specific introductions to new localities are many and various (Macdonald *et al*., 2003a,b; Pallewatta *et al*., 2003a,b; Ruiz and Carlton, 2003; Shine *et al*., 2003a,b). Consequently, it is difficult to formulate reliable generalizations in this field. It has been suggested , however, that most vertebrate introductions are deliberate (Fuller, 2003; Kraus, 2003), as are most introductions of terrestrial plants (Mack, 2003a), with the exception of particular groups including agricultural weeds (Richardson *et al*., 2003). In contrast, accidental introductions predominate for marine plants (Ribera Siguan, 2003), and the majority of invertebrate taxa (Cowie and Robinson, 2003).

When human settlers first occupied new lands, they brought plants and animals with them. Such introductions contributed to the impacts of these first human settlers on indigenous species and habitats, along with land clearance and other activities associated with early agriculture. This process continues with opening up of new lands to agriculture and development.

Increasing trade between nations, and especially between colonial powers and their colonies, was significant in increasing rates of introductions (Mack, 2003a). Such activities led to the deliberate dissemination of crops, other plants, and livestock within and between the Old and New Worlds, and many species were also accidentally introduced. The accelerated rate of introduction increased the probability of new species becoming established and invasive. Meyer (2003) estimates that the number of species introduced into French Polynesia in the last 250 years has been about 20 times greater than the number introduced in the preceding 2500 years.

Whilst IAS may be one legacy of a colonial past, new introductions (both authorized and unauthorized) have continued in the post-colonial era in many countries, for example, *Eucalyptus camaldulensis* (Hussain, 2003). Indeed, increasing international trade has only led to further acceleration in rates of introductions, which increased under GATT (General Agreement on Tariffs and Trade, 1947; replaced by the World Trade Organisation in 1995), and with the opening of new routes due to political and economic change.

The deliberate movement of species for ornamentation rather than utility is also an important consideration in human-mediated introductions. Early examples of this phenomenon include the activities of European plant collectors. Many thousands of garden plants have been introduced into Western Europe and some, e.g. *Rhododendron ponticum*, are now highly invasive. Ornamental plants were also transported between European colonies, again resulting in a number of significant IAS problems (e.g. *Lantana* and *Chromolaena* in Asia and Africa). Non-native plants continue to be moved around the world for the benefit of gardeners and landscape architects. Although fewer animals than plants have been translocated for aesthetic reasons, some were introduced to European colonies e.g., mammals and birds in to New Zealand. The pet and aquarium trade today continues such activities.

In addition to crops, livestock, ornamental species and other traded commodities, the volume and rate of movement around the world of people themselves has never been greater. Tourism as a popular pursuit developed in the 20th Century, and is still expanding. This increased human traffic increases opportunities for inadvertent, as well as deliberate, transport of alien species to new lands.

The international movement of people, equipment and materials carries with it the risk of accidental introductions. Organisms may easily be transported inadvertently with consignments, including in packing materials. For example, during the period 1985–95, the USDA Animal and Plant Health Inspection Service (APHIS) made more than 5,600 interceptions of alien insects on various types of wooden packaging, such as crating, pallets and dunnage. These insects arrived from more than 86 countries and represented 10 insect orders (Haack, 1998). Planes and ships themselves can harbor organisms in many different ways. Aircraft travel at such speeds that organisms which would be unable to survive a lengthy journey by sea can now be transferred between continents in a matter of hours. In earlier times, when ships' ballast comprised solid materials such as gravel or rocks, plant introductions commonly resulted (Mack, 2003a). Water is now commonly used as ballast, and the discharge of ballast water, along with hull fouling, has been identified as a key factor in the introduction of IAS into marine, estuarine and some freshwater environments (Colautti *et al*., 2003; Fofonoff *et al*., 2003; Fuller, 2003; Ribera Siguan, 2003).

In the context of IAS, human-assisted movement of species between countries tends to be the primary focus. It is important to note, however. that the movement of species by human agency within a country can also be an important factor in enhancing the spread (and hence impacts) of IAS. For example, the deliberate movement of cocoa planting material has been implicated in the rapid spread of the non-native cocoa pod borer *Conopomorpha cramerella* through Malaysia in the 1980s (Hassan Othman and Abu Hashim, 2003). In other cases, within-country movements of native species to areas outside their existing range have resulted in negative impacts on the biodiversity of recipient areas, for example, internal translocation of various fish species and the Cape bee in South Africa (Zimmermann, 2003). For freshwater vertebrates across taxa, the majority of recorded introductions in the USA are within-country translocations (Fuller, 2003). Within-country movement can be particularly critical where it involves the spread of IAS between separate land masses and individual islands, not least because islands tend to support particularly vulnerable populations of (often endemic) indigenous taxa. Although the sea ordinarily represents an effective barrier to natural dispersal, human movement within an archipelago can rapidly disseminate a species. For example, the coconut leaf hispa *Brontispa longissima* was accidentally introduced into French Polynesia in 1960, on ornamental palms imported from New Caledonia. The beetle quickly spread to all the Society Islands, then to the Marquesas Islands (1970), and to the Austral and Tuamotu Islands in the early 1980s (Meyer, 2003). Such within-country spread may be accelerated by the lack of effective quarantine systems for inter-island movement of materials, for example, as noted for the Marshall Islands (Vander Velde, 2003) and Palau (Holm and Michaels, 2003).

Understanding Vectors and Pathways for IAS Introductions

Knowledge and understanding of pathways and vectors for species introductions are key factors in interpreting historical patterns of introductions and predicting future invasions (e.g. Fofonoff *et al*., 2003), and are thereby critical to the development of effective strategies for the management of IAS threats (Richardson *et al*., 2003; Ruiz and Carlton, 2003). The identification of sources of IAS introductions is often a specific component of national programs to counter the invasive species threat, as in Namibia (Smit and Steenkamp, 2003).

The summary above of the impact of human activity on the movement of species indicates the large number and variety of potential IAS vectors and pathways. Unfortunately, for many existing IAS problems, (even those arising from deliberate introductions), the precise circumstances of introduction are not unambiguously documented. Particularly where the introduction occurred long in the past, the date, means and purpose of the introductions, and even the country of origin, may not be recorded (Haysom and Murphy, 2003). With more recent (accidental) introductions, it may be the case that early detection would have prompted measures to prevent establishment and spread. In other words, the fact that the species has become a problem can itself be indicative of the introduction event having gone unnoticed, making it difficult to determine the circumstances of introduction (except by informed speculation) after the fact.

Recent publications examining IAS problems on a regional basis (Kairo *et al*., 2003 for the Caribbean; Macdonald *et al*., 2003a,b for southern Africa; Pallewatta *et al*., 2003a,b for south and southeast Asia; Shine *et al*., 2003a,b for the Austral-Pacific) provide valuable country-by-country assessments of key species invasions and their impacts. They also re-emphasize that the precise circumstances of individual introductions are often not recorded. In general terms, at least three attributes of vectors/pathways have been related to the probability of introductions leading to establishment: the numbers of individuals introduced; the frequency of introductions; and the likelihood that the introduced individuals will be healthy (Fuller, 2003).

International Assistance and IAS Introductions

International assistance is defined here as the movement of people and materials in support of humanitarian and development objectives, particularly where these are sponsored by bilateral or international aid programs. From the perspective of IAS introductions, these programs share many important features with other human activities, such as trade and tourism, for example, methods of transportation (and the types of opportunities they provide for unintentional introductions). They also require similar policies and infrastructure for intercepting potential IAS. The key distinction is that international assistance activities are driven by humanitarian and development objectives, rather than commercial or political goals. Nevertheless, despite good intentions, developed countries can facilitate the introduction of IAS to other countries by such means (Wittenberg and Cock, 2001; Baskin, 2002; Reaser *et al*., 2003; Reaser, 2003, Macdonald *et al*., 2003b; Shine *et al*., 2003b).

This paper considers three broad types of international assistance, particularly in relation to developing countries:

- Development programs (particularly agriculture, (agro)forestry and aquaculture)
- Disaster relief programs
- Military assistance programs with a humanitarian remit (such as peace-keeping operations conducted under the auspices of the United Nations)

In each case, it is difficult to define precisely the full range of activities that should be included under each heading. For example should exchange of germplasm for crop improvement be excluded when the recipient nation is not a developing country, although developing countries may ultimately benefit from such research? There may also be some overlap between these categories, such as where disaster relief programs are implemented by military personnel. The following chapters outline the kinds of activities typically associated with international operations under each of these headings, and review some of the IAS problems that have resulted from such activities.

The available information on IAS as a result of international assistance programs is scattered, poorly documented, and difficult to come by. Gathering relevant information from published sources has therefore proved to be very difficult. Even recent reviews generally fail to quantify the particular contribution that assistance programs have made to the global increase in IAS problems (Haysom and Murphy, 2003). This reflects the general lack of available published data on the precise history of introductions leading to species invasions in many countries but it is clear that a significant problem exists which warrants further and more extensive study. IAS problems created by international assistance programs pose similar challenges to those arising through other vectors and pathways. Two features, however, make them a particular target for urgent, concerted action. Firstly, they are invariably directed at the most vulnerable human communities, where a loss of agricultural production or ecosystem services can have the most severe consequences for livelihoods. Secondly, they arise unintentionally from activities inspired by humanitarian motives, instigated by agencies with a strong interest in doing more good than harm. Such agencies would generally be expected to have both the human and financial resources to ensure that IAS problems are not imposed on the intended beneficiaries of their activities. Preventing or solving these particular IAS problems is therefore perhaps more achievable than many other IAS problems, particularly in developing countries. It is especially important to ensure that species known to be invasive are not deliberately spread.

In relation to IAS, it should be noted that international assistance programs are contributing to the solution as well as the problem. Reaser et al. (2003), for example, note examples of such projects supported by the US Agency for International Development, including: studies of IAS control methods in the Galapagos Islands; re-establishment of native fish populations in Bangladesh; environmental impact studies on control methods for water hyacinth in Uganda; support for the Working for Water Programme in South Africa. See also World Bank (2004) for Bank projects to address IAS in India, Mauritius Seychelles, South Africa, and trans-national efforts such as those focusing on water hyacinth control in Lake Victoria.

3 Development Programs

Background

Historically, many deliberate introductions of non-native species have been driven by the desire to enhance local self-sufficiency, food security and/or for economic development, for example in Bangladesh (Islam et al., 2003), Laos (Nhoybouakong and Khamphoukeo, 2003), and the Philippines (Sinohin and Cuaterno, 2003). Whether or not development assistance programs can be specifically implicated in individual introductions, there is no doubt that many IAS problems can be linked to the deliberate introduction of non-native species for agriculture, (agro)forestry, aquaculture and other activities which are often supported by such programs (Macdonald *et al*., 2003a; Pallewatta *et al*., 2003a; Shine *et al*., 2003a). In relation to southern Asia, for example, Elahi (2003) regards deliberate introductions in relation to food security, fuel needs, nutritional needs, reversing severe deforestation, and the need to develop aquaculture and cash cropping, as being particular sources of IAS introductions. In many cases, species chosen for deliberate introduction were selected specifically for their characteristics of high productivity, for example, the forestry tree, *Acacia auriculifomis* in Bangladesh (Islam *et al*., 2003). Although such characteristics do not automatically result in invasive behavior following introduction, they are amongst the traits that appear to be linked with invasive potential.

The following paragraphs first briefly review IAS introductions in relation to a number of activities: agriculture, (agro)forestry, aquaculture, biological control and construction projects. This is to illustrate the general nature of how IAS problems occur, although in these examples no links are made to international assistance. These activities are *typical of support provided by* international development assistance. A number of examples are also given where IAS introductions are *specifically linked to* international development assistance programs.

Agriculture

Whilst most of the major crop plants that have been disseminated so freely around the world have not become IAS, familiar species of domesticated livestock have become damaging invasive species in some situations where feral populations have developed. Notable examples include goats and pigs, and islands ecosystems have proven particularly vulnerable to their impacts (Coblentz, 1998). Reports of pests and diseases of animals being introduced with livestock are relatively infrequent. However, examples do exist, suggesting that there are legitimate concerns over the potential for such IAS introductions. For example, it is believed that the disease brucellosis was probably introduced into the USA with imported cattle (Wittenberg and Cock, 2001). Livestock movements may also facilitate the introduction of invasive plant species. For example, the giant sensitive plant *Mimosa diplotricha* and the blue rats tail *Stachytarpheta urticifolia* are believed to have been introduced to the Pacific island of Niue with imported cattle (Konelio, 2003).

In addition to vertebrates familiar as agricultural livestock, invertebrates have also been translocated around the world in support of agriculture in the broadest sense. For example, bee products are an important resource for poor communities in many parts of the world, and apicultural activities have resulted in IAS problems in a number of cases. The arrival in the 1990s of sacbrood, a viral pathogen, now affecting native *Apis cerana indica* bees in Malaysia, may be associated with the introduction of more productive *A. c. cerana* bees from China to improve local honey production (Hassan Othman and Abu Hashim, 2003). Bees themselves can also be a focus of concern; since its introduction to Brazil (and subsequent escape from a research facility) in the 1950s, the aggressive Africanized honeybee has spread through the Americas, causing livestock and human fatalities (Wittenberg and Cock, 2001).

Another IAS problem associated with introduced invertebrates relates to the giant African land snail *Achatina fulica*. This species has been deliberately introduced to many areas, generally as a food resource (Cowie and Robinson, 2003), often becoming established as an IAS. For example, the species was introduced to French Polynesia in 1967, where it rapidly became an agricultural pest, and predatory snails subsequently introduced to control it have devastated indigenous, endemic snail populations (Meyer, 2003).

Plants deliberately introduced for agricultural purposes other than to provide a staple human food source have also become IAS in some situations. For example, in the case of the introduction of elephant grass *Panicum maximum* to Vanuatu as pasture for cattle; livestock cannot eat the grass once it matures, but it out-competes native grasses where it becomes established (Maike-Ganileo and Horry, 2003). Similarly, tall fescue *Festuca arundinacea*, introduced to North America from Europe as a pasture grass, has invaded remnant prairies, displacing a diverse natural herbaceous plant community (Wittenberg and Cock, 2001).

Consignments of seeds for agriculture can carry with them weed seeds, leading to introductions of these species to new localities. This phenomenon is not associated exclusively with the spread of modern agriculture. Meyer (2003) suggests that during the initial human settlement of French Polynesia (by migrants from Samoa and Tonga between about 700BC and 700AD), around 50 of the 80 or so plant species introduced were accidentally translocated, including weeds accidentally introduced as seed contaminants. Nonetheless, the spread of modern agriculture has led to a wider distribution, and greater volume, of seed shipments. Mack (2003a) notes that there were few effective efforts to remove extraneous seeds from batches of crop seed until the late 20th Century, when provisions for such actions were introduced in Europe. Even then, the requirement for clean seed did not necessarily apply to consignments for export. Although regulatory instruments (and methods for cleaning crop seed) have developed considerably since then, contamination of traded seed with the propagules of other plant species is still a common phenomenon. For example, Enomoto (1999) reports that between 1994–95, at least 47 extraneous species were found in consignments to Japan of shipments of soybean from the US, and 26 species in shipments of legume seed from Australia. The Seed Health Unit (SHU) of the International Rice Research Institute (IRRI), Philippines, routinely quarantines and screens rice seed on import. In the period 1998-1991, the SHU found that 15% of incoming shipments were contaminated, and 20 weed species were detected (Huelma *et al*., 1996). *Echinochloa* spp. grasses were the most frequently intercepted weeds, but known invasive species such as itch grass *Rottboellia cochinchinensis* were also present. This study also provides some data on the micro-organisms that can be carried along with weed seeds in contaminated shipments. Seeds of *Echinochloa* spp. were found to harbor storage fungi *Penicillium* spp., *Aspergillus* sp. and *Rhizopus* sp., which cause rice grain discoloration. The range of organisms and materials that can be transferred in contaminated seed shipments is further illustrated by another study from the Philippines. Mew *et al*. (1999) list the contaminants detected by the SHU in rice seed shipments received from various regions of the world for the period 1989-1991 (see Appendix 1, Tables 1 and 2 of this report). These included soil, insects, weeds, and pathogens (fungi and nematodes). Some form of contamination was present in shipments from all parts of the world, but mainly from Africa and Asia. Many of the species listed are serious pests of cereals in general. Similar ranges of contaminant species have been detected at quarantine units in South America (Pineda-Lopez *et al*., 1999) and in India (Ghanekar and Varaprasad, 1999).

Although contaminated seed shipments are an obvious mechanism for the introduction of weeds, there is also evidence of invasive plants being introduced in other types of agricultural shipments. Consignments of straw and hay also have considerable potential to carry with them the seeds of a range of plants (Mack, 2003a). Whilst straw and hay might generally be expected to be produced close to the point of use, exceptional circumstances such as drought may impede local production, and result in importation from elsewhere (see Chapter 4). However, there is also an on-going international trade in these commodities, with many nations including Japan, Korea, Malaysia, Saudi Arabia, Singapore and Taiwan importing hay from elsewhere in the world (Mack, 2003a). Whilst Japan is described as perhaps the international leader in hay inspection for noxious, non-indigenous species, methods used by the Japanese Plant Protection and Quarantine Service do not eliminate the possibility of unwanted introductions, even of specific target species such as quack grass *Agropyron repens*. Hay imports to Japan have also provided the likely means of introduction of 9 out of 98 quarantine insect pests that became established in the country in the period 1917-99 (Kiritani and Yamamura, 2003).

In addition to weeds, agricultural shipments have significant potential as carriers of non-native insects and other pests. As with contaminated seed consignments, such translocations of pests undoubtedly have a long history. The following selection represents examples of such accidental introductions leading to IAS problems:

- The cassava mealy bug *Phenacoccus manihoti*, and cassava green mite *Mononycellus tanajoa*, were both introduced from Latin America to Africa, probably in the early 1970s on illegally imported cassava planting material (Herren and Neuenschwander, 1991)
- The sugarcane white grub *Pyllophaga smithi* (a melolonthid beetle) is believed to have been imported to Mauritius from Barbados in the early 20th Century, in soil containing rooted sugarcane (Mauremootoo *et al*., 2003)
- The mango leaf gall midge *Procontarinia matteiana* is believed to have been imported to Mauritius from India in the early 20th Century, on mango plants (Mauremootoo *et al*., 2003)
- The Natal fruit fly *Ceratitis* rosa is believed to have been imported to Mauritius from South Africa in 1953, on fruit (Mauremootoo *et al*., 2003)
- The Queensland fruit fly *Bactrocera tryoni* was probably introduced to Tahiti from New

Caledonia with infected fruits in 1970, and subsequently spread throughout most of French Polynesia (Meyer, 2003)

- The potato tubermoth *Phthorimaea operculella* was accidentally introduced to India in 1900, with seed potatoes from Italy (Diwakar, 2003)
- The woolly aphid *Eriosoma lanigerum* may have been accidentally introduced to India with nursery stocks imported from England in 1909 (Diwakar, 2003)
- The oriental chinch bug *Cavelerius saccharivorus* is believed to have been accidentally introduced to Japan with sugarcane seedlings imported from Taiwan in 1911 (Kiritani and Yamamura, 2003)
- The coconut mealy bug and potato cyst nematodes imported with planting materials are now considered IAS in the Philippines (Sinohin and Cuaterno, 2003).

The extent to which agro-ecosystems in developing countries can become dominated by non-native species is illustrated by the work of Haynes *et al*. (2003) who found that the earthworm communities of agricultural soils in South Africa consisted predominantly of exotic species accidentally introduced from Europe, India and West Africa.

(Agro)forestry

Plantation forestry using exotic trees has become an integral and crucial part of many national economies and environmental programs (Haysom and Murphy, 2003). Thus the plantation forestry sector in southern Africa, the primary source of timber and tannin bark, is entirely based on non-native tree species (Nyoko, 2003). Non-native trees and woody shrubs also provide a range of other products, such as firewood, fodder, and fruit (Nyoko, 2003), and thus contribute to the livelihoods of many of the world's poor. They may also be introduced for purposes that can broadly be described as environmental protection and enhancement: provision of shade, revegetation of denuded land, consolidation of soils, and so on. For example, a number of plants now considered IAS in Sri Lanka were originally introduced to protect river banks (*Mimosa pigra*), provide windbreaks (*Myroxylon balsanum*), to improve salt-affected soils (*Prosopis juliflora*) (Marambe *et al*., 2003). Consequently, there has been, and remains, a thriving movement of woody species around the world. However, trees have also been identified as one of the most significant groups of invasive plants (Richardson, 1998). Problems include direct and indirect displacement of indigenous biodiversity, hydrological effects, and allergenic responses in humans (Islam *et al*., 2003).

A recent analysis suggests that some 443 species of trees and woody shrubs are reported to be invasive somewhere in the world, of which 282 are recognized forestry trees, and 203 are species used in agroforestry (Haysom and Murphy, 2003). Based on data from 1996–97, 10 million hectares (8% of the land area) of South Africa are estimated to have been invaded by woody alien plants, a very large proportion of which have been deliberately introduced and disseminated for forestry (Richardson *et al*., 2003). Documented environmental damage caused by alien tree species in southern Africa includes stream flow reduction, change in soil nutrient status, reduction in species richness, increased biomass in some ecosystems, and genetic pollution (Van Wilgen *et al*.2002 in Pierce *et al*. 2002).

Globally, plantation forestry often draws on a relatively small pool of fast-growing trees, including species of *Acacia*, *Eucalyptus*, *Gmelina*, *Pinus*, *Populus*, and *Tectona*, many of which are now reported as invasive in a number of countries (Haysom and Murphy, 2003). Agroforestry programs, and projects using woody plants to revegetate lands and/or consolidate soils, also tend to draw on a relatively small pool of species, often legumes (e.g. species of *Acacia* and *Leucaena*). Some of these genera are very high on the list of woody plant IAS reported from many parts of the world (Haysom and Murphy, 2003). The legume families contain a particularly high proportion of invasive species (Hughes, 1994), and feature highly in reports of woody species invasions from around the world (Haysom and Murphy, 2003).

Aquaculture

Historically, many species of fish have been introduced to freshwater systems around the world, in attempts to create fisheries where they previously did not exist, or to enhance pre-existing stocks (Colautti *et al*., 2003). In some cases, recent deliberate introductions of animal species are mostly of fish, as in Bangladesh (Islam *et al*., 2003). Escape from aquaculture is a significant means by which non-native fish are introduced into the wild. Given the infrastructure and methods used in aquaculture such escapes may be regarded as virtually inevitable (Fuller, 2003). Consequent IAS problems include direct and indirect displacement of indigenous biodiversity, including through the introduction of diseases, for example epizootic ulcerative syndrome in Bangladesh (Islam *et al*., 2003; Fuller, 2003). Tilapia have been particularly widely introduced, and have become IAS in many countries.

A notable example of an IAS problem arising from fish introductions relates to the Nile perch *Lates niloticus*. This species was first introduced into Lake Victoria, East Africa, in the mid-1950s to supplement dwindling fish stocks. Although the population took 20 years to build up, the perch has had a substantial impact on the ecological balance of the lake (Ogutu-Ohwayo, 1998), and is credited with having caused the extinction of more than 200 endemic fish species (ISSG, 2000). The introduction of Nile perch to Lake Victoria has been described as one of the greatest evolutionary and ecological disasters precipitated by mankind (Colautti *et al*., 2003; for further details see Kaufman, 1992). However, the economic consequences are complex. For local fishermen, the perch has provided a good source of income and food, and Kenya, Uganda and Tanzania generate foreign exchange from Nile perch fillet exports to various destinations in Europe and Israel. However, where fish was once the cheapest source of protein for the average Ugandan, the demand from fish processing plants has driven the price beyond the means of many local people, whose per capita consumption has decreased (Ogutu-Ohwayo, 1998).

Aquacultural activities are not limited to those involving fish, but also draw on a range of aquatic invertebrates. Globally, Ribera Siguan (2003) suggests, the movement of shellfish for aquaculture is amongst the most important vectors for accidental introductions of marine plants, and also serves as a means of accidental introduction of pathogens and other species (Wittenberg and Cock, 2001). A snail is amongst the most devastating IAS to arise from deliberate introductions of aquatic invertebrates. The golden apple snail *Pomacea canaliculata* was imported from Latin America to Southeast Asia in about 1980, with the intention of developing aquaculture programs using the species as a high protein food source. Following its escape, the species has become a serious pest of rice in the region (Cowie, 2002). During the 1980s, it has been estimated that the snail caused losses of approximately US$1 billion to rice production in the Philippines alone (Naylor, 1996).

Biological control

Classical biological control involves the deliberate introduction of non-native species to suppress populations of IAS. Where it is well-targeted, this is a very valuable technique for the management of certain invasive species. However, some relatively early attempts, and particularly those involving the release of generalist predators, have left an unfortunate legacy, where the biological control agent itself has become invasive. Some examples are given below.

The house crow *Corvus splendens* was introduced into Malaysia to control oil palm insect pests, and now displaces other bird species. It represents a potential source of human health problems as well as being a considerable nuisance in urban and settlement areas (Hassan Othman and Abu Hashim, 2003). Birds introduced for rat control in French Polynesia, notably the swamp harrier *Circus approximans* and the great horned owl *Bubo virginianus*, have also had negative impacts on the indigenous avifauna. So too has the common myna *Acridotheres tristis* introduced to control introduced wasps (Meyer, 2003).

Non-native fish have often been introduced as biological control agents, particularly against aquatic weeds and invertebrate pests (Fuller, 2003). A number of invasive alien fish recently introduced to Bangladesh, for example, were imported for such purposes (Islam *et al*., 2003). Mosquito fish *Gambusia* have been distributed all over the world in attempts to control mosquitoes, although species of native fish (populations of which are often suppressed by the aggressive introduced *Gambusia*) are more effective in this role in many areas (Fuller, 2003).

The predatory rosy wolf snail *Euglandina rosea* has been introduced to a number of localities in ill-conceived attempts to control (introduced) giant African land snails (Cowie and Robinson, 2003). This has resulted in important non-target impacts, including the extinction of a number of endemic snails in French Polynesia, Hawaii and Mauritius (Mauremootoo *et al*., 2003; Meyer, 2003; Wittenberg and Cock 2001).

Compared with some other types of deliberate introductions, many introductions of exotic species for biological control have at least been relatively well catalogued (see Cock, 1985 for the Caribbean). Although poorly regulated biological control programs remain a potential danger, international standards have been set for the use of the technique (FAO, 1996; Greathead, 1997). Rigorous screening for potential impacts on non-target biodiversity is clearly an essential part of any biological control program (Thomas and Willis, 1998), and is now a feature of all responsible activities in this area of work.

Construction projects

Infrastructure projects such as roads, dams, and irrigation canals may also provide pathways for IAS introduction and spread. Construction projects may involve the importation of a wide range of materials, equipment and vehicles, providing opportunities for accidental species introductions. Bulk timber and wood packing are important vectors for IAS introductions. Over two years, from July 1999 to June 2001, Australian authorities made a total of 836 interceptions of insect pests on sawn coniferous timber from New Zealand, Canada and the USA (Pheloung, 2003). The potential for imported vehicles to act as vectors for species introduction can be illustrated with data from New Zealand, where all used cars are inspected on arrival in the country, and where nearly 30% (based on 1999–2000 data) have required decontamination due to the presence of soil or other organic material (Hayden and Whyte, 2003).

Meyer (2003) lists a number of construction projects in French Polynesia that have contributed to the introduction or within-country spread of IAS. The introduction of black rats and predatory snails to Fatu Hiva is linked to the construction of a hydro-electric station. Similarly, the introduction of *Miconia* to the Marquesas Islands is linked with road construction, and to the Austral Islands with the building of water tanks. In Palau, the marine hydroid *Eudendrium carneum* is exhibiting invasive dynamics, having been accidentally introduced with a pontoon bridge imported from China in 1997, as a temporary replacement for a collapsed structure (Holm and Michaels, 2003).

Development Assistance Programs

Most of the major international aid agencies contribute funds to agricultural, (agro)forestry, aquaculture and other development programs in developing countries. The total amount given to such programs, as a proportion of total aid, has fallen over recent years but still comprises a key component of aid budgets. For example, in 1995, Norway devoted 6.2% and Australia 3.3% of their total aid budgets to agricultural development (Randel and German, 1998). Funding is most commonly channeled through the recipient country, where a number of governmental bodies, national and international non-governmental organizations (NGOs) and inter-governmental organizations (IGOs) such as the International Agricultural Research Centres (CGIAR), may be involved in any particular development project. Alternatively, aid agencies may direct funds to organizations in the developed world, to support activities such as crop improvement programs.

This review is concerned primarily with research and implementation projects that involve the exchange of biological material between countries, e.g. for crop, tree, or livestock improvement, or for the trial of new species. There is evidence that such activities have increasingly, and unwittingly, led to the introduction of species that subsequently become invasive. Two types of problem can be identified: the accidental introduction of invasive species along with new agricultural and other material, and invasive behavior displayed by the very species that are deliberately introduced for agricultural and other purposes. Each of these is considered below.

It is worth noting that increased awareness of the threats posed by IAS is leading countries in receipt of development assistance to scrutinise proposed introductions more closely. For example, moves have been made by some countries to assess the risk of introduction of agroforestry trees and shrubs (Tucker and Richardson, 1995). In some cases, proposed introductions have been rejected altogether. For example, American Samoa rejected a proposal to introduce Bermuda grass *Sorghum halepense* under an Australian international assistance programme, because of the highly invasive character of this species (Tuinoula, 2003). Hellin and Larrea (1998) found that farmers in Guinope (Honduras) were using live barriers to control soil erosion, as recommended by an NGO programme in the 1980s. However, they tended not to use species promoted by the programme (napier grass *Pennisetum purpureum* and king grass *P. purpureum x P. typhoides* (*P. glaucum*)), but increasingly employed sugarcane and fruit trees. Whilst the grasses were more effective in retaining soil, farmers pointed out that they were invasive and that there was little demand for the amount of fodder produced. The species chosen by farmers were less effective in retaining soil, but contributed to the farm household in terms of domestic consumption and/or the sale of the products of the live barriers. Despite such examples of increased awareness amongst some recipients of development assistance, it appears that some agencies and NGOs continue to recommend known invasive species for use in development programmes.

Unintentional introductions

Many countries regularly exchange biological material for agricultural research and trial. As the examples above illustrate, contaminated shipments of agricultural seeds and other plant material can, in general, provide a potent mechanism for the accidental introduction of a range of non-native organisms. It is therefore very likely that the number of species dispersing accidentally via the agricultural development pathway is substantial. The information available suggests that weed seed, microorganisms and small insects are particularly problematic because of the difficulties of detecting them. There appears to be an increase in the number of species being accidentally transported, and this is likely to be related to the increase in the exchange of germplasm between countries; the problems extend throughout the developing world. Although quarantine systems are detecting and screening out many of these unintentional introductions, the potential economic and social impact of invasions by some of these species is enormous, and few of the existing IAS have been successfully controlled. Some particular examples of invasions arising from accidental introductions under development assistance programs are as follows:

Itch grass (*Rottboellia cochinchinensis*) is native to parts of tropical Asia, and is now a major weed problem in cereal fields in Central and South America. Itch grass severely limits the production of maize, rice and other crops in smallholder farms. Yield losses of over 50% have frequently been recorded, up to 81% in maize in Honduras (Sharma and Zelaya, 1986). Available evidence suggests that itch grass has been accidentally transferred with grain seed exchanged between international and national research organizations. For example, surveys within Thailand in the 1980s identified only one biotype of the weed that occurs throughout the country. However, a second biotype (confirmed by genetic characterization of populations) was recorded from Suwan experimental farm from the northeast of the country. Trials of imported seed from IARCs are conducted on this farm. It is very likely that the weed was introduced into the Americas via the same type of pathway.

Plant nematodes such as *Meloidogyne*, *Heterodera*, *Globodera* and *Pratylenchus* species cause crop losses or severe reductions in yield in many parts of the world. There is good evidence that plant nematodes are being accidentally spread through trial plantings of new crop material in national agricultural experiment stations. Several surveys in developing countries have demonstrated the presence of a major nematode species, new to a country or region, and restricted to an experimental farm. For example, an assessment of plant nematodes in Papua New Guinea (PNG) showed the presence of the citrus nematode (*Tylenchulus semipenetrans*) in a grove at the Lowland Agricultural Experiment Station in East New Britain Province; the species was not found elsewhere and is alien to PNG (Bridge and Page, 1982).

Intentional introductions

A major feature of agricultural and forestry development has been the trial of new species. Most food and livestock species have been translocated during the last few hundred years; plantation and agroforestry tree species particularly during the last 50 years (Haysom and Murphy, 2003). In general, the main criteria used to judge the performance of crop, tree and animal species in a new environment have been their adaptability and yield. Until recently, at least, little or no concern has been shown for the invasive potential of the species. Although many exotic crop and livestock species are not inherently detrimental to native floras and faunas, a significant number of species have proved to be invasive. Reaser *et al*. (2003) note the following examples of activities under development assistance projects by which the US and other countries have promoted, facilitated or carried out deliberate introductions of invasive species: development of aquaculture based on Tilapia, carp, bass, trout and other invasive fish species; introductions of golden apple snail into Southeast Asia; use of invasive woody plants such as eucalypts and *Leucaena leucocephala* in (agro)forestry programs. Examples of such intentional introductions are examined below.

Many species of grasses and legumes have been introduced into Bolivia over the last 50 years, for trials as improved pasture plants on experimental farms near Santa Cruz. Most of the more recent introductions have been made from Australia, South Africa, the USA, and from other countries within South America. A significant proportion of these introductions have been supported by international development assistance programs. Between the mid-1970s and early 1980s, over 65 species/varieties of grass, and over 140 species/varieties of legume were imported for trial. The trials were based purely on assessment of the species as forage plants; invasive potential was not taken into account. At least eight of the grass and legume species have now naturalized in the Santa Cruz area and are spreading. The ecological impacts, particularly on local species are unknown.

Water hyacinth (*Eichhornia crassipes*) is a prolific free-floating weed of freshwater systems, and is now present in most of the tropical and sub-tropical regions of the world. It originates from the upper Amazon river basin in South America. Its promotion by international assistance agencies for biomass production is partly responsible for its rapid spread in the developing world, particularly in Africa. The plant's rapid growth rate makes it a strong candidate for biomass production, but also contributes to its invasiveness; growth rates have been estimated at 6.8% weight/day in the Nile Delta (Batanoumy and el Fiky, 1975). As an invasive species, water hyacinth affects water flow, electricity generation, transport, water quality, indigenous biodiversity and fisheries (Hill *et al*., 1999). Today, it puts at risk substantial international aid investments in water resource development. In 1997, the World Bank had 150 water resource management projects (active or in the pipeline), either already affected or at risk, based on investment of US$16 billion in loans to projects valued at more than US$45 billion (Joffe and Cooke, 1997).

Substantial efforts have been made to control water hyacinth. Biological control, using insect agents, has been successful in some areas, e.g. Lake Victoria in East Africa funded by World Bank and the Global Environment Facility (GEF). Nonetheless, the range of the weed is still expanding and large investments are now being made by development agencies to implement existing control technologies and to develop new ones.

The promotion of fast-growing exotic trees and woody shrubs, for a range of purposes, has been an active feature of many national and international agricultural and forestry programs since the mid-1960s. In the developing world, these activities have received considerable support from international aid agencies. The following represent examples of IAS problems that have arisen as a result.

Cordia alliodora, a Central American species, was introduced to Vanuatu as a potential timber plantation tree under a development assistance program. Not only did it prove to be unsuitable as a forestry species, it has subsequently invaded indigenous habitats (Tolfts, 1997). The species was also introduced for forestry in Tonga, and has shown invasive dynamics there (Space and Flynn, 2001).

The thorny legume *Prosopis juliflora* has been widely introduced outside its native range in Mesoamerica. It has a range of uses, including as a source of fuel wood, fodder and soil stabilizing ground cover, but has become invasive in a number of recipient countries. This issue has recently come to particular prominence in Kenya, where the plant was introduced under the Fuel Wood/Afforestation and Extension Programme (1982). The project was implemented locally by the Kenya Forestry Research Institute (KEFRI) and the Forestry Department, with sponsorship from the Australian government through the FAO. Concerns over the environmental damage caused by the spread of *Prosopis* have led Kenya's National Environmental Management Authority (NEMA) to accuse the FAO and local institutions of deliberately introducing an invasive plant, contrary to the provisions of the Noxious Weed Act (Mbaria, 2004).

As in Kenya, the introduction of *Prosopis* to Ethiopia (in the late 1970s/early 1980s) has resulted in a substantial species invasion. Up to a quarter of arable grazing land has been overtaken by the plant, soil nutrient dynamics have been adversely affected, and the thorns are a hazard to the local population. There is currently much interest in determining who (ultimately) was responsible for the introduction, with both the FAO and state forestry agencies attracting blame (Irby, 2004).

4 Disaster Relief Programs

Background

Whatever their cause, food shortages often prompt the importation of materials from outside the affected area, carrying with it the risk of species introductions. Kiritani and Yamamura (2003) note that a surge in the number of stored-product insect pests introduced to, and establishing in, Japan occurred in the period 1945–65, associated with substantially increased grain imports to cover post-war food shortages. In response to the 1980-81 drought in New South Wales, Thomas *et al*. (1984) report that massive shipments of hay for livestock feed were brought into the affected area from other localities (some up to 900km away) in Australia. Sampling of 26 kg hay bales revealed an average content of 68,700 seeds; the seed of 105 extraneous plant species were recovered from just 38 bales. Although most of these species were considered innocuous, all but one bale contained seed of at least one restricted or prohibited plant species.

Severe food shortages arising from natural disasters (or, indeed, human mediated causes) often prompt a response from the international community, in the form of emergency provision of food aid. Natural disasters also often lead to other forms of humanitarian assistance, for example, reconstruction projects. The movement of materials, equipment and people involved in disaster relief programs provides a mechanism for the potential introduction of non-native species. As with land exposed to military conflict (see Chapter 5), the physical disturbance and removal of vegetation cover caused by certain kinds of natural disaster may make some areas particularly vulnerable to invasion by non-native plants species.

Disaster Relief Programs

Natural disaster relief and assistance is specifically recognized as a potential pathway for introduction of IAS to Tonga, with bulldozers, chainsaws, food and seed consignments cited as examples of vectors for introductions by this route (Foliaki, 2003). The Natural Disaster Management Unit is amongst the government departments/agencies which are concerned with IAS in Niue (Konelio, 2003).

Within disaster relief programs, food aid provision mostly operates through the United Nations World Food Programme (WFP, established 1961), bilateral programs, or international and national NGOs. In the case of the WFP, member countries generally contribute food commodities directly, although funds or services are provided in some cases. By the early 1990s, the WFP had managed the transportation and delivery of over 4.7 million tons of food to over 90 developing countries; approximately one-third of this was handled on behalf of bilateral donors and NGOs. Ocean shipping has been the WFP's main transportation means to recipient countries (Shaw, 2001).

Most food aid comes in the form of grains (such as maize, rice and wheat) or beans. Statistics from national quarantine services of developing countries show that contaminant species are an enormous problem in such shipments. In Kenya, for example, the Plant Health Inspectorate Service (KEPHIS) report the frequent occurrence of seed borne pathogens, weed seeds, and insect storage pests in food grain shipments. In 1996, the Indian Directorate of Plant Protection, Quarantine and Storage (DPPQS) reported eight fungi, three bacteria, one virus and 44 weed species in a shipment of wheat from Australia (DPPQS, 1999). Several countries have reported major IAS problems arising from food aid shipments, including the following examples.

Congress weed (*Parthenium hysterophorus*), an annual plant which originates from Mesoamerica, has become one of the most serious invasive weeds in India where it is now present in most parts of the country. The plant invades agricultural land, where it is a contaminant of various crops and can cause a reduction in yield (e.g. in sunflower). It also invades scrub, wastelands and road verges. However, the main problems are that it causes allergic eczematous contact dermatitis in humans and is highly toxic to livestock. Impacts on human health and livestock have been well documented in Australia where the weed is also a problem (McFadyen, 1995).

Parthenium seems to have been introduced into India with grain shipments, and subsequently appears to have been spread to Sri Lanka by Indian peace-keeping forces (Marambe *et al*., 2003). In 1988, it was first recorded in Ethiopia, where it appears to have arrived with food aid grain shipments from subtropical North America; by 1999, the weed was widespread in eastern Ethiopia, and spreading more widely and threatening national parks (Anon., 1999; Wittenberg and Cock, 2001).

The Larger grain borer (*Prostephanus truncatus*) is a beetle, native to Mesoamerica, and probably parts of South America, where it is a pest of farm-stored maize. The borer can attack and damage a range of crops, but breeding and serious damage only occurs in maize, cassava and wheat. Whole grains are attacked before and after harvest. In the 1960s, the borer was reported from Israel and then Iraq, but in neither case did it become established; in the latter case, the maize had been imported from the USA under the World Food Program (Al-Sousi *et al*., 1970). The borer was reported from India in 1987 (Verma and Lal, 1987), and has also been recorded in Africa, where its initial introduction (to Tanzania) is believed to have been with maize imported in a food relief shipment in the late 1970s (Makundi, 1987; Anon, 2000a). In Tanzania, weight losses of 35% have been reported in maize, and mean losses to stored maize and cassava have been estimated at 9% in affected areas, compared with 1% elsewhere (Golob and Hodges, 1982; Golob, 1988). During the 1980s, the borer was reported from Togo, Kenya and Burundi (Makundi, 1987), and has since spread to many countries in Africa, reaching South Africa and Namibia in 1999 (Anon., 2000a), although it has still not occupied the full area of its potential range in the continent or within countries. Huge investments have been made in containment and control. In the 1990s, FAO executed a phytosanitary project in eastern and southern Africa to curtail the spread of the borer. Biological control of the insect has been implemented in some countries, and has been shown to have significant impact.

5 Military Assistance Programs

Background

The classification of military deployments as a form of assistance can be contentious, according to circumstances. This review is concerned only with military assistance with a clear humanitarian remit, such as peace-keeping operations conducted under the auspices of the United Nations. In a broader context, however, there is little doubt that military activities in general have contributed to the movement and establishment of invasive species.

There are a number of respects in which military activity can tend to increase the rate of IAS introductions (e.g. Fosberg, 1957). Increased movement of personnel and materials is accompanied by the enhanced risk of accidental translocation of, for example, seeds clinging to military equipment, supplies, packing cases, clothing, and the wheels of aircraft. Thus the accidental introduction of congress weed, *Parthenium hysterophorus*, in parts of Sri Lanka seems to be linked to the Indian Peace Keeping Force (Marambe *et al*., 2003). In addition, military conflict often results in substantial disturbance of existing habitats, and the creation of areas of bare ground, enhancing the probability of establishment of weedy species. In addition to accidental introductions, various crop and livestock species have been deliberately introduced into countries in conflict, to guarantee a food source.

Even attempts to mitigate environmental damage caused by military activity may have resulted in new IAS problems, for example through the deliberate introduction of Bermuda grass and other subsequently invasive plants in attempts to revegetate islands denuded during World War II (Fosberg, 1957). In other situations, however, military personnel may be recruited to assist in invasive species control activities, as with the temporary involvement of the Zambian army with removal of water hyacinth from waterways in the early 1990s (ECZ, 2003).

Military Assistance Programs

Military assistance to maintain order and stability in an area following conflict, generally operates through the United Nations with the deployment of international peace-keeping forces. As the examples above illustrate, there is a significant risk of species introductions associated with military activities in a general sense. Examples of introductions arising from peace-keeping activities are given below. Increasing awareness of the potential threat of IAS movements during such operations have led to preventative measures being instigated, in at least one case. Authorities in Australia recognized the risk of unwanted species introductions that might arise from the transfer of materials between its military base in Darwin, Northern Territory, and its peace-keeping operations in East Timor, and measures were introduced to clean vehicles before transport between localities (Anon., 2000b; Wittenberg and Cock, 2001).

The Western corn rootworm beetle (*Diabrotica virgifera virgifera*) is a major pest of maize in North America; losses and control operations have been estimated at up to US$1 billion annually. The insect was accidentally introduced from North America into Serbia in 1992. It was first reported close to Belgrade international airport, where it was present in an area of about 60ha (Baca, 1994). By 1997, about 20,000 ha of maize in Serbia were heavily infested (Kuhlmann and Van der Burgt, 1998), and the pest had spread to much of the Balkan region, subsequently spreading to Italy (1998), and Switzerland (2000). As the rootworm is likely to be able to spread to all areas in Europe where maize is grown (EPPO, 2001), the area of crop at risk is about 14 million hectares. Military assistance from the USA to Eastern Europe during the Balkan conflict has been identified as the likely pathway of introduction of this pest.

Whilst biological invasions may not have resulted, it is interesting to note that there is also evidence of the translocation of species from the Balkans to the USA as a result of the same program of military assistance. Cowie and Robinson (2003) record that 231 interceptions of snails were made on returning military equipment in the immediate aftermath of activities in 1999. However, the data of Robinson (1999) indicate that accidental importations on military cargo account for an extremely small proportion of snails intercepted by the US Department of Agriculture.

6 Existing Prevention Schemes

Prevention is the most effective way of addressing species invasions. The probability of deliberate introductions leading to IAS problems can be reduced through appropriate risk analysis schemes (which include risk assessment and risk management), 'screening out' those candidate species which are most likely to pose a threat if imported. If accidental introduction occurs, then early detection may allow eradication, but this becomes increasingly difficult as an IAS spreads Thus there is a window of opportunity to prevent further problems from an IAS. For example, the khapra beetle *Trogoderma granarium* was detected in Malaysia when it occupied just one isolated rice store, and was successfully eradicated, whereas attempts to eradicate other IAS which had already spread further through the country were unsuccessful (Hassan Othman and Abu Hashim, 2003).

Prevention Frameworks

Government and intergovernmental plant and animal health services have long been engaged in the prevention of introductions of pests and diseases in the agricultural sector. Consequently, prevention frameworks tend to be better developed in relation to IAS threats to agriculture than to the wider environment. A range of international regulatory instruments exist which have relevance to the prevention of accidental IAS introductions (Shine *et al.*, 2000; Shine, 2003 Macdonald *et al.*, 2003b; Shine *et al.*, 2003b) — see Box 2. The International Plant Protection Convention (IPPC) underpins action in plant protection. The IPPC is responsible for setting criteria for phytosanitary measures. These measures are adopted by the World Trade Organisation (WTO) to ensure fair trade between its member countries. Under the IPPC, other regional organizations and agreements have been created to protect the interests of groups of neighboring countries with similar plant protection problems. The IARCs involved in germplasm transfer also have quarantine units which work in harmony with national or regional quarantine organizations (Kahn and Mathur, 1999). Setting criteria for protecting animal health, at the international level, is the responsibility of the Office International des Epizooties (OIE).

In addition to international frameworks, there are numerous relevant instruments and activities at national level, although they vary considerably between countries (see Kairo *et al.*, 2003; and national reports in Macdonald *et al.*, 2003a; Pallewatta *et al.*, 2003a; Shine *et al.*, 2003a). Systems for managing the threats posed by unwanted species introduction, such as risk assessments and inspections, are particularly well developed in certain countries, such as Australia and New Zealand (Pheloung, 2003; Hayden and Whyte, 2003). Reviews of systems in place in South Africa and the USA are given by Richardson *et al.* (2003) and Cavey (2003) respectively. The scale of quarantine activity at the borders of the USA is illustrated by the fact that authorities there have made annual interceptions of more than 1.5 million prohibited or infected plants and plant products, and 40,000 to 50,000 plant pests (USDA, 1999 cited in Cavey, 2003).

In addition to regulatory frameworks, many countries now have active projects to deal with species invasions, from planning initiatives to eradication programs for particular IAS (see Kairo *et al.*, ; 2003 and national reports in Macdonald *et al.*, 2003a; Pallewatta *et al.*, 2003a; Pierce *et al.*, 2002; Shine *et al.*, 2003a; World Bank, 2004).

Box 2
International Regulatory Instruments Relevant to Prevention of IAS

Plant health

The International Plant Protection Convention (IPPC) provides for the development of international phytosanitary standards (ISPMs). ISPMs cover matters such as pest risk analysis, import and release of exotic biological control agents, guidelines for the establishment of pest free areas and guidelines for pest eradication programs. Recent standards (2003) now take greater account of environmental concerns and coverage of taxa that may impact on natural as well as agricultural systems.

For information on IPPC see www.ippc.int

Animal health

The Office International des Epizooties (OIE) covers pests and diseases of animals, but not animals as IAS. The OIE have codes (International Animal Health Code for Mammals, Birds and Bees and the International Aquatic Animal Health Code) which set out standards on import risk analysis and risk management measures for specific pests and diseases.

For information on OIE codes see — www.oie.int

Effectiveness and "Gaps"

Despite the prevention frameworks in place, it is clear from current IAS problems that some pathways for IAS movement are still 'open' Why should this be so? There may be several reasons:

- Traditional risk management schemes, such as inspections and quarantine, may be outstripped by the sheer volume of trade.
- Developing countries may be particularly challenged because of lack of resources and training.
- In general, the threat of some groups of microorganisms may have been underestimated in the past.
- Some pathways of introduction of IAS (such as intentional introductions of species which also prove to be invasive), and/or the threats to some ecosystem types may not be fully appreciated by all relevant sectors of society.

With respect to the first point, Buck (2003) reports some illuminating statistics from Hawaii, demonstrating the effectiveness of rigorous inspections in intercepting accidental species introductions. The Hawaii Department of Agriculture dramatically increased the levels of inspection of incoming aircraft at Kahului, Maui over seven periods of three to four weeks. During these inspection "blitzes", 125 insect species new to Hawaii were found, having arrived with aircraft cargo, and there were 1401 interceptions in total. In a normal year, the number of interceptions for the whole of Hawaii would be expected to be 782. Although only a small proportion of these 'new' insect species are likely to be potential invaders, these data illustrate not only the effectiveness of rigorous inspection, but also the likely numbers of accidental introductions that go undetected in the absence of such scrutiny of imported materials.

Capacity to enforce prevention instruments (e.g. to operate an effective quarantine system) is often lacking at a national level, particularly in smaller countries (Murphy, 2003). Lack of capacity may be reflected in inadequate inspection facilities, taxonomic expertise, access to information, and/or paucity of other resources. In addition, national systems may concentrate mainly on international boundaries, and be only poorly developed in relation to internal translocation of materials and organisms (e.g. Shine, 2003, Macdonald *et al*., 2003b; Shine *et al*., 2003b). Given the level of inspection that is usually possible, current quarantine measures may have only a small influence on the worldwide spread of alien species (Cowie and Robinson 2003).

More generally, efforts are now being made at international and national levels to address environmental and agricultural concerns about IAS by developing new tools for risk assessment and risk management. The IPPC is working in collaboration with the CBD on the broadening of existing standards for phytosanitary measures to include environmental concerns. Some countries such as the UK have developed risk assessment schemes that include modules for assessing pathways and receptor ecosystems.

7 Closing Pathways for IAS Resulting from International Assistance Programs

The origins of many IAS problems, particularly in the developing world, are poorly understood. Knowing how, and from where, IAS are being introduced is crucial for the development of effective prevention and early detection frameworks. The available information on IAS as a result of international assistance programs is scattered and difficult to come by. Some cases of IAS have been poorly documented but it is clear that international assistance programs may provide pathways and vectors for the introduction of IAS. Preliminary discussion by CGIAR stakeholders in 2001 re-emphasized the importance of this issue, and gave broad support to the need for action to address it — see Box 3.

Addressing pathways and vectors for IAS that result unwittingly from international assistance programs will contribute to the general strengthening of prevention frameworks overall. In order to develop detailed recommendations for appropriate measures and mechanisms to prevent IAS introductions on the back of international assistance activities, more detailed information on the extent of the problem and the vectors and pathways involved is urgently needed. Part of the focus should be on case studies in order to elucidate more fully constraints in relation to existing prevention schemes. Nonetheless, there are a number of points that are worth consideration in advance of a fuller analysis and these are discussed below.

Some Immediate Considerations and Actions

The first logical step would be to raise awareness within aid agencies themselves of the potential consequences of IAS introductions arising from development activities. It is especially important to disseminate information about species which are known or likely to become invasive. Awareness raising booklets and other materials are now available from GISP and the Invasive Species Specialist Group of IUCN (ISSG). The ISSG's booklet which covers the world's worst IAS (ISSG, 2000) could be used to help aid-agencies learn more about the issues. Some authors (e.g. Macdonald *et al*., 2003b) have highlighted that invasive species do tend to have common biological characters (Box 4); thus this particular aspect could be factored into awareness raising initiatives. It should be noted, however, that one of the more powerful predictors of potential invasiveness is whether a species has been invasive elsewhere (Williamson, 1996).

Addressing IAS issues within development programs will be easier than in disaster relief or military assistance programs. This is because the short time frameworks and the logistical complexities of those latter types of programs raise some difficult issues in terms of screening for IAS. Nevertheless some measures may be possible,

Box 3
Invasive Alien Species, Agricultural Development, and the Aid Trade

At a session organized by CAB International and the Global Invasive Species Programme (GISP), the U.S. National Invasive Species Council (NISC) and the World Bank's Environment Department, CGIAR centres and donors identified the major invasive alien species issues in their sectors and discussed the priorities for addressing these. Workshop participants agreed that:

- Invasive alien species can have a significant impact on development, affecting sustainability of livelihoods, food security and essential ecosystem services and processes.
- Targeted development assistance programs have reduced the threat or impact of particular invasive alien species.
- Development assistance projects and emergency food aid programs have been significant pathways for the introduction of serious new invasive alien species to poor countries, either through contamination of imported plant and animal resources, or the deliberate introduction of beneficial species which subsequently become invasive and damaging.
- Cooperation between agricultural, environmental and related ministries will be essential to effective prevention and management of invasive alien species.

Participants noted that:

- The status of invasive alien species problems in developing countries is very poorly known relative to other regions, and CGIAR centres can contribute to assessment.
- Action against invasive alien species is constrained by a lack of awareness at the national and development agency level, where there is a need to quantify the costs of invasive species problems.
- Centres are often challenged to deliver short term benefits in productivity from new agricultural introductions, without sufficient knowledge on potential invasiveness of new plant and animal species or varieties. This identifies an urgent need for predictive tools to evaluate invasiveness.
- Besides direct impacts on agricultural production, e.g. by invasive pests, alien plant and animal material can pose a serious threat to the erosion of valuable genetic resources, particularly in areas of crop origin.
- Genetically modified organisms (GMOs) to the extent that they are potentially invasive and damaging, should be considered in programs on invasive alien species.
- Microbial systems have received far too little attention as potential areas of invasion and agricultural/environmental impact.
- There are few truly effective barriers to species spread today, which creates a need to anticipate and understand emerging and potential problems, to prioritize these and to be proactive.

such as using past experience to focus inspections on likely high risk IAS associated with particular pathways.

For development programs, aid agencies should take action based on the precautionary principle and risk assessment before introducing non-native species "Best practice" for the prevention and management of species invasions is reviewed by Wittenberg and Cock, (2001), and summarized by Murphy(2003), Sherley (2003) and Waage (2003). Aspects of international scientific cooperation in this regard are discussed by Macdonald (2003). The same assessment activities should also be considered for programs involving the supply of materials that may have a risk of being contaminated with IAS to reduce the risks of unintentional introductions.

Key actions for international actions to address IAS in assistance programs include:

- Promoting awareness raising and information tools about IAS

Box 4
Some Common Biological Characters of Invasive Alien Species

- Rapid individual growth rate
- Strong dispersal ability
- Large reproductive output
- Broad tolerance of variation in environmental conditions
- Species known to be invasive elsewhere

For general information about some of the world's most invasive species see the database of the Invasive Species Specialist Group—www.issg.org—and the website of the Global Invasive Species Programme—www.gisp.org.

- Promoting the development of voluntary 'codes of conduct' which give guidance on the responsibilities of exporters and importers and other stakeholders.
- Supporting the development of risk assessments for species being considered for deliberate introductions. Such schemes have been developed for particular types of species in some regions, for example agroforesty trees (see Tucker and Richardson, 1995)
- Developing and disseminating case studies and toolkits to assess the economic costs of IAS, including their impact on development programs
- Increased capacity building to identify, prevent, and manage IAS in developing countries
- Strengthened regional coordination to address IAS.

In addressing the threat of IAS introductions via development programs, disaster relief and military assistance, it is important to understand the constraints that many countries face, such as lack of capacity and training, in developing and enforcing prevention frameworks for IAS introductions. These constraints may not always be linked to the 'development status' of a country. Furthermore, better regional co-ordination of activities has been consistently identified as a requirement for improved prevention and management of species invasions (Sherley, 2000; Kairo *et al*., 2003; Macdonald *et al*., 2003b; Pallewatta *et al*., 2003b; Shine *et al*., 2003b). Although such approaches may be complicated by the geopolitical complexities of a region, the potential value of developing systems for sharing information and other resources is considerable.

It should be noted that materials moving outside conventional trade pathways (including movements related to international assistance programs) often fall outside of the scope of prevention frameworks (Shine, 2003; Macdonald *et al*., 2003b; Shine *et al*., 2003b). Thus, simply improving regular trade control systems will not be sufficient in itself. Measures need to be taken to bring international assistance activities into the orbit of these frameworks and mechanisms, or at least systems of equivalent, if not greater, rigor. Given the circumstances of many international assistance activities, a 'fast track' approach may be appropriate, but this should not be at the expense of adequate scrutiny of potential vectors and pathways for IAS introductions.

Finally, existing IAS problems that have resulted from past international assistance activities also need to be addressed, although there may be conflicts of interest where an environmentally damaging species is making some contribution to local livelihoods.

Appendix —
Contaminant Species in Incoming Rice Seed Shipments at the International Rice Research Institute (IRRI), Los Banos, Laguna, Philippines

Table 1. Detection of insects, weed seeds, and soil in incoming rice seed shipments received from various regions of the world at the Seed Health Unit, IRRI*

	Origins of rice shipments					
Pests / pathogen	*Asia*	*Africa*	*Europe*	*North America*	*South America*	*Pacific*
Insects	+	+	-	-	+	-
Sitotroga cereallella	+	+	-	+	+	-
Cryptolestes ferrugineus	+	+	-	-	-	-
Rhizoperta dominica	+	+	-	+	-	-
Tribolium confusum	+	+	-	-	-	-
Weeds						
Aeschenomene sp.	+	-	-	-	-	-
Cyperus compactus	-	+	-	-	-	-
C. difformis	-	+	-	-	-	-
Digitaria sp.	+	-	-	-	-	-
Echinochloa sp.	+	+	-	+	+	-
Ischaemum rugosum	+	-	-	-	-	-
Paspalum sp.	+	-	-	-	-	-
Scirpus juncoides	+	-	-	-	-	-
S. supinus	+	-	-	+	+	-
Stellaria media	+	-	-	-	-	-
Soil	+	+	+	+	+	-

* Based on data from 1989–91.

Table 2. Fungi and nematodes frequently detected in rice seed imports received at the Seed Health Unit, IRRI*

	Origins of rice seed imports					
Pests / pathogen	*Asia*	*Africa*	*Europe*	*North America*	*South America*	*Pacific*
Pyricularia oryzae	+	+	-	-	-	-
Drechslera oryzae	+	+	+	+	+	-
Fusarium moniliforme	+	+	+	+	+	-
Gerlachin oryzae	+	+	+	+	+	+
Sarocladium oryzae	+	+	+	+	+	-
Trichoconis padwickii	+	+	+	+	+	+
Curvularia spp.	+	+	+	+	+	+
Phoma spp.	+	+	+	+	+	+
Tilletia barclayana	+	+	+	+	+	+
Aphelenchoides besseyi	+	+	-	+	+	-

* Based on data from 1989–91.

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